Compliments of
Dabney H. Maury, Jr.

Test of High Duty Pumping Plant Under Ordinary Working Conditions.

BY
DABNEY. H. MAURY, Jr., M. E.,
Peoria, Ill.

A paper presented at the Springfield Meeting of the Illinois Society of Engineers and Surveyors, January 27, 28, 29, 1897.

UNIVERSITY OF ILLINOIS
CHEMISTRY DEPARTMENT

ARTHUR WILLIAM PALMER
MEMORIAL LIBRARY
1904

621.64
M44
Pam cop. 1

TEST OF HIGH DUTY PUMPING PLANT UNDER ORDINARY WORKING CONDITIONS.

DABNEY H. MAURY, JR., M. E., PEORIA.

Tests of steam pumping plants are of so frequent occurrence as under ordinary circumstances to hardly warrant the reading of a description of one of them as a paper before an Engineering Society.

Tests of this sort of machinery are, however, generally made for acceptance; and, where the incentive to show good results takes the form of a bonus in case of success, or fines, or other penalties, or even rejection, in case of failure, no effort is spared to make the plant show the best efficiency of which it is capable. Expert manipulators of the particular class of machinery—generally skilled employes or the manufacturers themselves—picked firemen, picked coal, perfectly clean boilers, carefully selected packings and lubricants, repeated trials to determine the best working conditions allowable under the specifications—all combine to secure results which, afterward, in actual working practice, are rarely, if ever, attained.

The test of the plant of the Peoria Water Company, which forms the subject of this paper, was made under ordinary working conditions. No effort was made to improve the condition of any part of the boilers, pumps or auxiliaries in any way whatever for the trial. The boilers, which are generally cleaned about once every five or six weeks, had been running nearly that time when tested, and owing to recent deterioration in the boiler compounds used, were much more coated than usual with scale and were leaking slightly. The plant had been in operation a little over five years. There were some small leaks in valves, pipes and stuffing boxes. The regular engineers and firemen were employed. No attempt was made to alter steam pressure nor cut-off, notwithstanding the fact that it was known that these were not at the point of highest efficiency.

It was the writer's desire to test the whole plant just as it was ordinarily operated, with a view to determining, as nearly as possible, the direction in which improvements could be made. One of the principal benefits which it was hoped might be derived from the tests,

p13430

was the improvement of the feed-water return system, with a consequent reduction in cost of boiler compounds and saving of oil, and better performance, fewer repairs and longer life of boilers.

While no other test has been made since the one to be described, the operation of the plant in the meantime has shown to a certain extent some of the improvements resulting from the changes made, and the paper will include a brief description of these changes and of the results obtained.

DESCRIPTION OF PLANT.

The plant tested was the steam pumping plant of the Peoria Water Company, which consists of:

Three Worthington Compound Condensing Duplex Vertical High Duty Pumping Engines, rated at 7,200,000 gallons capacity each per twenty-four hours, at piston speed of 140 feet per minute. The pumps are numbered, respectively, 611, 612 and 613.

Three batteries of Heine Water Tube Boilers, each battery having two boilers of 200-horse power each, or 1,200-horse power in all six boilers. The boilers are numbered from east to west and from 1 to 6.

And the following auxiliary pumps, compressors, etc.:

Pumps Nos. 1 and 2.—Boiler-feeders. These are located one on each side of hot well and between boilers Nos. 4 and 5, and exhaust into hot well.

Pumps Nos. 3, 4 and 5.—Air compressor and water pumps, with high pressure water-plungers attached to yokes on the piston rods. These pumps are set on brackets on engine room wall and exhaust into hot well.

Pumps Nos. 6 and 7.—Used to return condensed jacket steam to boilers; are located on first floor of main pump grating, and exhaust into hot well.

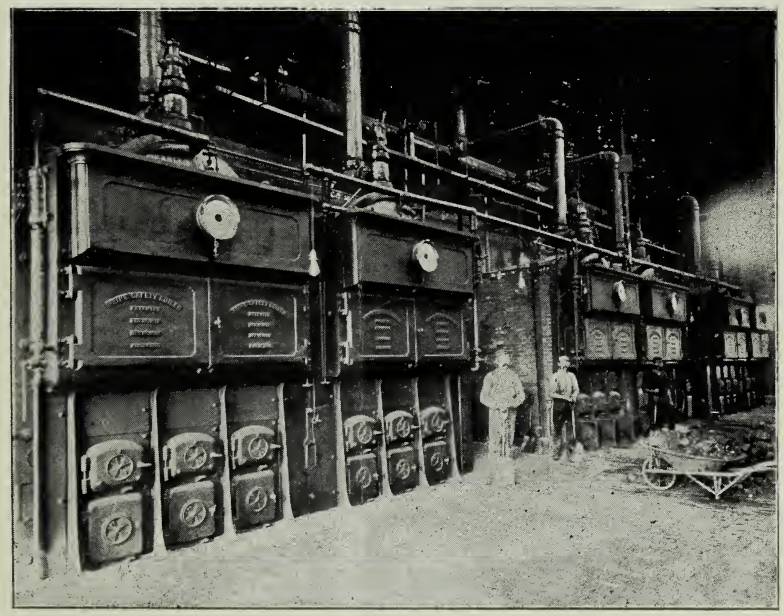
Pump No. 8.—Used for draining pump-pit or dry-well, and located at bottom of same, exhausting into sewer.

Pumps Nos. 9 and 10.—Used to create vacuum in condensers, and to pump condensed steam from main engines up into the hot well. Are located at bottom of dry-well, about on a level with condensers, and exhaust into hot well.

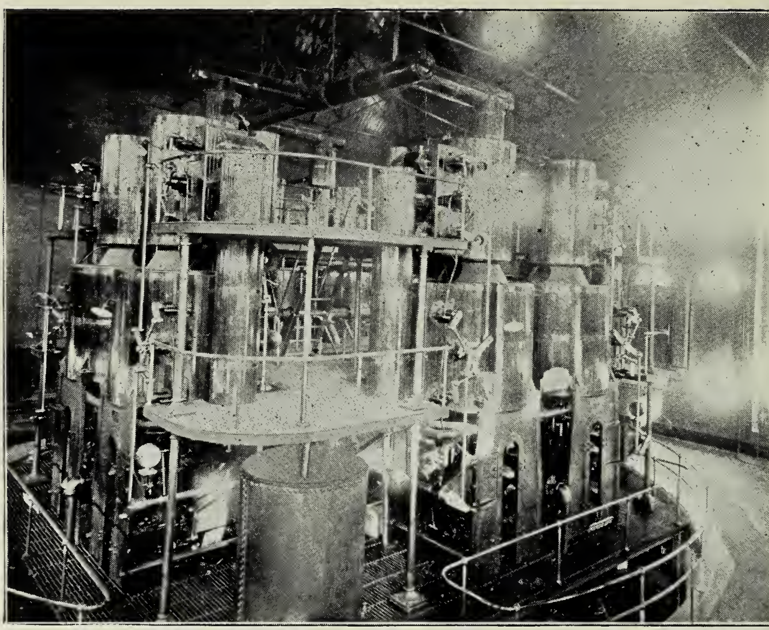
Pump No. 11.—Duplex, Two-Stage Air-Pump, made by New York Air Brake Company, and known as their "No. 3 Duplex Pump." Used for compressing and pumping air into accumulator tank and air chamber on force main. Is set against wall of engine room, and exhausts into hot well.

And one 5x10-inch Horizontal Automatic Cut-off Engine, built by John T. Noye, Buffalo, and used only for driving dynamos to furnish electric light. This is located in a corner of engine room, and exhausts into sewer.

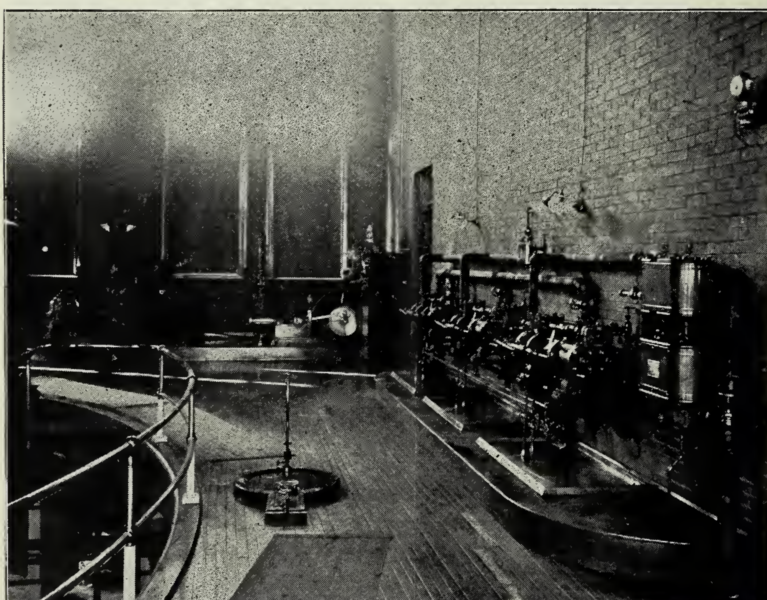
There is a steam trap for returning into the hot well the steam condensed in main steam lines.



View of Boiler Room, Pumping Station of the Peoria Water Co.



View of Engine Room, Pumping Station of the Peoria Water Co.
Showing Worthington Pumping Engines Nos. 611, 612 and 613. The Mercury Column is shown against the wall at the right of the picture.



View of Engine Room, Pumping Station of the Peoria Water Co.
Showing Electric Light Engine and Dynamo, and Air Compressor Pumps Nos. 3, 4, 5 and 11.

The three condensers are of the surface type, and are set one on each suction pipe of the main engines, at the bottom of the dry-well. Over the hot well, which is located in an alleyway between boilers Nos. 4 and 5, is a closed heater. Exhaust steam from the auxiliaries (except that from No. 8 and the electric light engine), goes into the closed heater, where it imparts some of its heat to a coil through which the feed-water is being pumped on its way to the boilers, and thence passes, partly condensed, down into a coil of pipe in the hot well, where its condensation is completed by the feed-water which surrounds it. This feed-water is principally the condensed steam from the main engines and auxiliaries, the deficiencies due to leakage, exhausts not returned, etc., being made up by the admission of fresh cold water from the mains. The boiler-feeders draw this feed-water from the hot well and pump it through the coil in the heater, just described, into the boilers.

As but one main pumping engine is ordinarily required to supply the city with water, the test was made on one pump only, which was No. 612. Boilers Nos. 5 and 6 alone were used. The electric light engine was not run, nor were pumps Nos. 3 and 4 (compressors); pump No. 7 (jacket-pump); pump No. 8 (dry-well pump), nor pump No. 9 (vacuum pump). Pump No. 2 was used only to deliver feed-water from the hot well into the barrels in which it was weighed, and whence it was drawn by pump No. 1 and forced through the heater into the boilers.

The accompanying photographs give an idea of the general arrangement of the plant.

DESCRIPTION OF TESTING APPARATUS AND PREPARATION OF SAME.

Much time and attention were given beforehand to the standardization of thermometers, pressure and vacuum gauges, scales and other instruments, and in this direction it was found necessary, in the absence of laboratory facilities, to devise, in some instances, apparatus for the purpose.

Thermometers.—A Centigrade Thermometer, made of Jena Normal Glass, reading from 0° to 100°, and graduated to tenths of 1° C. was purchased, and was sent to Yale Observatory for test. By means of the certificate of corrections furnished by the observatory, this thermometer could be used as a standard of comparison between the limits of its graduations. Another thermometer graduated to fifths of 1° C., and reading from 100° to 200° C., was used for comparisons at higher temperatures. A sufficient number of cheaper thermometers, suitably graduated, were also purchased. A mercury well 7½ inches long by 1½ inches inside diameter, was set vertically inside of a 4-inch pipe which was closed at top and bottom and fitted on one side with a valve for the admission of steam, and a valve for the admission of cold water; and on the other side, near the top, with an outlet valve. By means of this 4-inch jacket the mercury well could be surrounded by a bath at any desired temperature from 12° C., the temperature of the well water, up to 170° C., the temperature of steam at the maximum boiler pressure. The thermometer to be tested was suspended in the mercury well with the standard thermometer, the bulbs being at the same level, and the mercury was stirred till its temperature was practically uniform, when simultaneous readings were taken. Fifteen to twenty readings were taken at each observation, and observations were made for each 5° C. To each thermometer was attached a numbered tag, and the record of its test was made on blanks prepared for the purpose, and of which the accompanying blank is a sample.

Standardization of Thermometer by Comparison with Standard Thermometer.

Maker and No. of Standard Thermometer........................

Maker and No. of Thermometer Compared......................

Date..............189.. Observers { .... / ....

No.	Reading of Standard Thermometer.	Correction for Standard.	Actual Temperature of Well.	Reading of Thermometer Compared.	Correction for Thermometer Compared.	REMARKS.
......	....	....	....	....	....	....
......	....	....	....	....	....	....

Pressure and Vacuum Gauges and Indicator.—There are about twenty-five pressure gauges and three vacuum gauges in use at the plant, the majority of which were used during the test. An attempt to compare these gauges with the standard gauge at the pumping station developed the fact that the latter was itself incorrect, as were also the only other so-called standard gauges available in Peoria; and as it was important that the gauges should be accurately standardized, efforts were made to find a mercury column. Diligent search by the writer in Chicago failed to discover one; and the literature on the subject seemed also to be deficient. Only one type of column was found to be described. In this type the level of the mercury in the reservoir could not be seen, and it was necessary to calculate the same from the height of mercury in the column. This made it essential that the glass column should be of uniform bore. It seemed that a much better and cheaper instrument might be constructed, and accordingly one was finally devised by the writer and made by him and by the regular employes at the pumping station, out of ordinary pipe and fittings and common glass tubing.

In the Peoria Water Company's mercury column the level of the mercury in the well can be seen; irregularities of bore of tubing do not affect the reading, and no corrections of any sort are necessary, save for temperature. As the column is located inside the building where the temperature does not vary more than 20° throughout the year, even this correction is rarely, if ever, needed. The column answers every purpose better than the expensive instruments described in works which treat of them, and can be used with either air or steam or water pressure.

The record of the comparison of each gauge with this mercury column was made in duplicate, one copy being pasted to the back of the gauge and the other left in the record book. Below is found a sample of blank form for record:

Standardization of Pressure-Gauge by Comparison with Mercury Column.

Maker and No. of Gauge..................................

Date.............189.. Observers { .... / .... }

Temperature of Mercury..................................

Barometer in Room ....

No.	Mercury Column, in inches (Observed)	Mercury Column, in inches (Corrected)	Mercury Column, in Pounds.	Gauge in Pounds.			Correction in Pounds.	REMARKS.
				Up.	Down	Mean		
......	....	....	....	......	......	......	....	....
......	....	....	....	......	......	......	....	....

One inch Mercury @ 70 degrees Fahr.=0.493 lbs.
One inch Water @ 70 degrees Fahr.=0.0361 lbs.

The Taber Indicator used in the test was standardized by means of the same mercury column. The vacuum gauges were tested with a mercury manometer, made of a plain, straight glass tube, one end of which was coupled by means of a short piece of rubber tubing to the pipe on which the gauge to be tested was set. The other end of the tube was immersed in a glass beaker of mercury, and a common yard stick tied to the tube gave the readings in inches of mercury. The results were recorded on blanks similar to those used for the pressure gauges.

SCALES.—There were used in the tests two large rolling mill scales, on wheels, for weighing feed-water; one dormant warehouse scale or platform wheelbarrow scale, for weighing coal; one smaller platform scale for weighing Calorimeter condensing water, and one small grocer's scale for weighing the small amount of condensed water coming from the Calorimeter. All of these scales were previously tested by the local weighmaster and the writer, and a table of corrections for each made out.

Calorimeter.—The Barrus Continuous Flow Calorimeter, as described on page 380, Carpenter's Text Book of Experimental Engineering, was used during the test, and the results were afterwards checked by the ordinary barrel Calorimeter. In this connection it should be stated that the results given by the Barrus Calorimeter showed superheated steam; but as it was found very difficult, under the existing circumstances, to get a reliable figure for the constant flow of the Calorimeter, and as it was deemed improbable that there was superheat, the results were disregarded and the steam was assumed as dry—an assumption which later observations have shown to be approximately correct.

Coal Analysis.—A sample of coal was taken from each wheelbarrow, and from all of these small samples, after crushing and careful mixing, a sample of several pounds was secured. All of this was powdered, passed through a fine screen, and a sample from this was taken for analysis by Dr. Theodore Breyer, of Peoria, with the following results:

Moisture	7.45	per cent.
Ash	12.49	"
Carbon	59.55	"
Hydrogen	3.42	"
Sulphur	3.90	"
Oxygen and nitrogen	13.19	"
	100.00	per cent.

Repeated approximate analyses of the sample gave the fixed carbon in the fuel as 42.95 per cent., and the fixed carbon (or "fixed combustible," as suggested by Dr. Emery) in the coal, dry and free from ash, as 54 per cent.

Calculations of the heating value of the fuel from the ultimate analysis by Dulong's law showed results varying from 9,645 B. T. U. per pound of fuel, up to 9,903 B. T. U. per pound of fuel, according to the figures used for the heating values of the several elements, and the method of applying the formula. The lowest figure, 9,645 B. T. U., was obtained by using the formula given in Article 344 of Carpenter's Text Book of Experimental Engineering, and allowing for the latent heat of evaporation of the water formed by the combustion of the hydrogen. The highest figure, 9,903 B. T. U., was obtained by applying Berthelot's figures in Dulong's formula as given in foot note to page 633 of Kent's Mechanical Engineers' Pocket Book, and not allowing for the latent heat of evaporation of the water formed by the combustion of hydrogen. An average of all the results as figured from the ultimate analysis gives 9,750 B. T. U. per pound of fuel.

But the calculations of the heating value of the same sample from the proximate analysis, as in the table on page 634 of Kent's Pocket Book, show much higher values, the figures being 10,830 B. T. U.

In the tabulation of the results of the test, Items 27, 28, 29, 30, 63 and 68 show separate results based on each of the two calculations of heating value, and their wide variation (over 11 per cent.) clearly illustrates the possible error in any given method of arriving at the thermal value of this sort of fuel by calculation based on its chemical constituents.

FLUE GAS.—A flue gas sampler was constructed of a net work of ½-inch perforated pipe, this being so distributed over the whole area of the flue, as to insure the collection of a fair sample of the gases passing along to the stack. An iron door was built across the flue between boilers 4 and 5, so that no air could get into the flue except what passed through the settings of boilers 5 and 6.

As the chemical apparatus for testing the flue gases could not be made to work satisfactorily on the day of the test, the analysis of the gases is not given here. Tests made afterwards, however, under as nearly as possible similar conditions, showed a slight excess of free oxygen in the flue.

THE TEMPERATURE OF FLUE GASES was determined by a high temperature thermometer kindly loaned by the University of Illinois.

THE DRAFT was measured by an U-tube manometer.

THE TEMPERATURE OF THE FURNACE was not taken because of lack of suitable instruments.

THE ANEROID BAROMETER used to determine the atmospheric pressure was compared with the mercurial barometer of the local Government weather observer.

The apparatus used to weigh the feed-water consisted of two large rolling-mill platform scales, each supporting a tierce of capacity of about 250 gallons. These tierces were alternately filled by the boiler feeder No. 2, which pumped water from the hot well into the top of the tierces. After the full tierce had been weighed, it was allowed to discharge into a third tierce which lay on the floor between the two scales; and from this tierce the water was pumped by No. 1 boiler feeder through the heater into the boilers. The total feed-water pumped was accurately weighed in this way, while that proportion of this total which consisted of fresh water from the mains fed into the hot well to make up the deficiencies caused by leakage, etc., was measured by a water meter which was repeatedly tested.

The jacket steam and steam returned by the trap were determined by carefully noting all the conditions of operation of jacket pumps and trap during the test, and afterwards running the jacket pump and trap under similar conditions, except that the returned steam and water were discharged into barrels partly filled with cold water, the increase in weight and temperature of the water being noted.

For determining the head against which the main pumping engine was working, the readings of the gauge were checked by means of the known difference in levels in the well and in the reservoir, the friction in mains being added to this difference in head. The calculations for main friction were themselves checked by a large number of readings of a gauge on the force main, taken, first, when the pumps were idle, and then when they were working under the conditions of the test.

To determine the leakage of the valves in the water cylinder, the heads of the upper and lower force chambers were alternately removed, and the water flowing past each set of suction and discharge valves was led into a bucket of known capacity and the time of filling noted. The leakage past the plungers was determined in somewhat the same way, except that a weir box and hook gauge were used to measure the water. Observations were made with the plunger at the end, and at the middle of the stroke.

The steam used by the several auxiliary pumps was determined by running the respective pumps, after the test, under as nearly as possible the conditions as to speed, steam pressure, load and back-pressure, which obtained during the test. The steam was exhausted under the proper pressure into a large tierce partly filled with water, and the increase in weight and temperature of the water in the tierce noted. While the weights thus obtained are known to be fairly correct, not so much confidence could be placed in the determination of the temperature, as it was difficult to so stir the water in the large tierce as to secure a fair reading on the thermometer. The inaccuracies, however, are not important, as they could not appreciably affect the general result.

The work performed by the several auxiliaries was calculated in each case from the observed conditions.

The strokes of the main pump were given by the counter attached thereto, which was checked repeatedly and always found correct. The indicator cards were taken in turn from the upper and lower sides of the high and low pressure pistons, in each of the two engines composing the No. 612 Duplex Pump. Four complete sets of cards, eight cards in each set, were selected from those taken during the test. The mean effective pressure was figured from these cards by measuring the area with the simple little Planimeter shown herewith, invented and patented by John Goodman, of Leeds, England.

During the test, the several observers were stationed as follows:

Two men weighed the coal, both keeping tally, and checking results after each wheelbarrow was weighed. These men also read and recorded, every fifteen minutes, the temperature and draught of flue

Peoria Water Co., Peoria, Ill. Indicator Card.

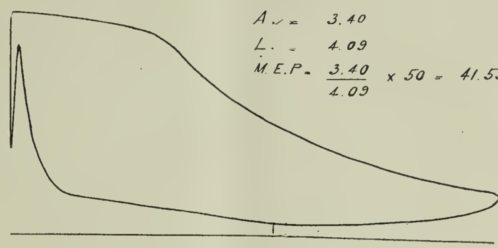
17. (5) # 1 Side

Diagram from Pump No. 612 **Cylinder** Top H.P

Diameter of Cylinder 25 ; Diameter of Rod 5½ ; Stroke 37 ; Clearance ;

Date May 15th 1896 ; Time 4 06 P.M. ; End of Cylinder ; Scale of Spring 50 ;

Boiler Gauge 107 ; Vacuum Gauge 26¾ ; Rev. per minute 21½



A = 3.40

L = 4.09

$$M.E.P. = \frac{3.40}{4.09} \times 50 = 41.55\#$$

Peoria Water Co., Peoria, Ill. Indicator Card.

18 (5) # 1 Side.

Diagram from Pump No. 612 **Cylinder** B.H.P.

Diameter of Cylinder 25 ; Diameter of Rod 5½ ; Stroke 37 ; Clearance ;

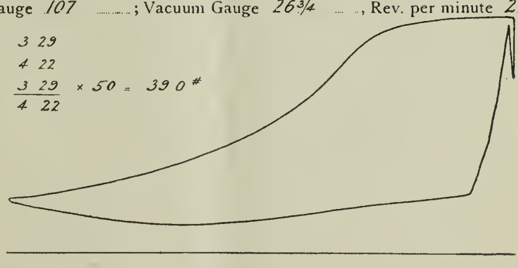
Date May 15th 1896 ; Time 4 12 P.M. ; End of Cylinder ; Scale of Spring 50 ;

Boiler Gauge 107 ; Vacuum Gauge 26¾ , Rev. per minute 21½

A = 3 29

l = 4 22

$$M.E.P. = \frac{3\ 29}{4\ 22} \times 50 = 39\ 0\#$$



PEORIA WATER CO.,
PEORIA, ILL.
INDICATOR CARD.

19 (5) # 1 Side

Diagram from Pump No. 612 Cylinder B.L.P.

Diameter of Cylinder 50 ; Diameter of Rod 5½ ; Stroke 37 ; Clearance ;

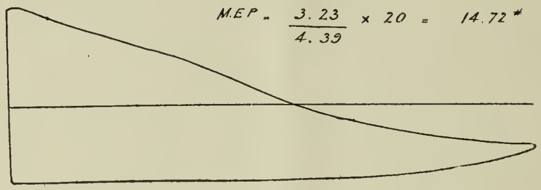
Date May 15th 1896 ; Time 4 51 P.M. ; End of Cylinder ; Scale of Spring 20 ;

Boiler Gauge 106 ; Vacuum Gauge 26¾ ; Rev. per minute 22

A = 3.23

L. = 4.39

M.E.P. = $\frac{3.23}{4.39}$ × 20 = 14.72#



PEORIA WATER CO.,
PEORIA, ILL.
INDICATOR CARD.

20 (5) # 1 Side

Diagram from Pump No. 612 Cylinder B.L.P.

Diameter of Cylinder 50 , Diameter of Rod 5½ ; Stroke 37 , Clearance ;

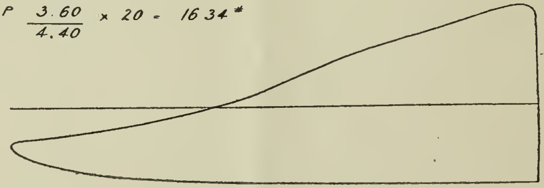
Date May 15th 1896 , Time 4 45 P.M. ; End of Cylinder ; Scale of Spring 20 ;

Boiler Gauge 106 ; Vacuum Gauge 26¾ ; Rev. per minute 21

A 3.60

L 4.40

M.E.P $\frac{3.60}{4.40}$ × 20 = 16.34#



gases, and the pressure on the two boiler gauges. Two weighed the feed-water, checking each other's observations, and recorded the readings of the hot and cold water meters and the thermometers set on the lines leading from hot well to barrels, from barrels to heater, and from heater into boilers. Two made the calorimeter tests. Two took indicator cards. The engineer on regular duty during the test noted every fifteen minutes the reading of the counter and of the steam, water and vacuum gauges on the main engine, and as often as possible measured the stroke of the main engine; recorded the air pressure on accumulator tank, the speed of the condenser pump No. 10, and the pressure on the counter-charge side of the accumulator. He also recorded the time of starting and stopping, and the speed of such auxiliaries as were used from time to time. An observer at the reservoir kept records of the stage of water there; another noted the level of the water in the well every fifteen minutes, and struck the signals on the gong which notified the other observers of the instant at which readings were to be taken, while the writer gave general attention and supervision to the various departments.

After a three hours' preliminary run, in which all hands were given the needed practice and drilling in their several duties, the test was begun at noon on May 15th, 1896, and was continued for seven hours.

The test was started with a four-inch clean fire on the grates, the ash-pits being cleaned immediately after starting. The steam pressure was at its normal, and the level of water in the boilers was marked by strings tied around the water glasses. The test was closed with the fires, steam and water under the same conditions as at the start, and the water level, draught and steam pressure were kept as constant as possible during the trial.

I take this occasion to acknowledge, with thanks, the valuable assistance rendered during the test by Messrs. Jacob A. Harman, C. E., Peoria; Ralph P. Brower, Class '97, Civil Engineers, U. of Ill., and J. T. Stewart, of Peoria.

The following are the principal dimensions of boilers, engines and auxiliaries, and the record of the test:

OWNERS OF PLANT, PEORIA WATER COMPANY, PEORIA, ILLINOIS.

Date of Trial, May 15th, 1896; Duration of Trial, Seven Hours;
Principal Dimensions of Boilers, Flues, Stack, Etc.

1. Boilers Nos. 5 and 6, each—		
87 Tubes, 3½-inch outside diameter, 16 ft. long	1,276.3	sq. ft.
2 Water-legs (heated on one side only).....	35.0	"
½ of main drum, 16x4 ft..................	73.0	"
Total heating surface each boiler..........	1,384.3	sq. ft.
" " " both boilers.........	2,768.6	"

2. Grate surface each boiler, 4 ft. 5 in.x6 ft. 7 in...	29.04	sq. ft.
" " both boilers	58.08	"
Rocking grate bars, 9 rows of bars, 12 bars to one foot; space between each pair of bars, on top, about equal to width of one bar.		
3. Ratio of heating surface to grate surface	47.67	
4. Super-heating surface, none....................	0.00	
5. Cross-section of stack, 5 ft. 4 in. square	28.44	sq. ft.
Height of stack above boiler room floor........	155.00	feet.
" " " " grates	153.00	"
6. Cross-section of flue where it enters stack	32.00	sq. ft.
" " " between boilers Nos. 4 and 5, where door was put in to shut off air......	29.50	"
7. Principal dimensions of engine No. 612, Worthington Compound Duplex Vertical High Duty Pumping Engine—		
Diameter of high pressure cylinders (2)...	25	inches
" " low " " "...	50	"
" " water plungers (2)..........	21	"
" " steam piston-rod, between high pressure and low pressure pistons.......	5	"
Diameter of steam piston-rod below low pressure piston.......................	5½	"
Diameter of plunger rod.................	5¼	"
Average stroke for whole 7 hours........	3.09	feet

PRINCIPAL DIMENSIONS OF AUXILIARIES.

8. *Pump No. 1.*—Boiler Feeder, Worthington Horizontal Duplex, 5¼-inch and 3½-inch by 5-inch stroke. Ran constantly at 83 complete strokes per minute, pumping water from weighing barrels into boilers, against a pressure of 103.45 lbs., plus the friction in pipes.
9. *Pump No. 2.*—Boiler Feeder, same make and dimensions as No. 1. Ran intermittently lifting water when necessary from hot well into weighing barrels. Total time of running, 140 minutes, averaging 60 strokes per minute.
10. *Pump No. 5*—Worthington Horizontal Duplex Air and Water Pump, with ⅝-inch water plungers connected by yoke to main piston-rods. Dimensions, 5¼-inch and 3⅜ inch, and ⅝-inch by 5-inch stroke. Ran 14 minutes at 71 complete strokes per minute, pumping 111.2 cubic feet of free air against pressure of 116 lbs., and 68 cubic feet of water against pressure of 758 lbs.
11. *Pump No. 6.*—Jacket Pump. Worthington Horizontal Duplex, 3 inches and 2 inches by 3-inch stroke. Ran continuously during test, averaging 27½ strokes per minute, pumping 5,390 lbs. of condensed jacket steam into boilers.

12. *Pump No. 10.*—Condenser Pump. Worthington Horizontal Duplex Air Pump. Ran continuously during test at 37.5 complete strokes per minute, creating an average vacuum in condensers of 25.34 inches, and lifting 43,316 lbs. of condensed steam a vertical distance of 35 feet into hot well.

13. *Pump No. 11.*—Two-stage Air Compressor. New York Air Brake Co.'s No. 3 Duplex Pump, with two steam cylinders 7 inches in diameter, one air cylinder 5 inches in diameter and the other air cylinder 7 inches in diameter, and a stroke of 9 inches, common to all four pistons. Ran intermittently a total of 65 minutes during test, averaging 18.5 complete strokes per minute. Compressed 720 cu. ft. of free air to a pressure of 116 lbs.

14.	Steam pressure on boilers by gauge................	103.45 lbs.
15.	Absolute steam pressure (barometer 14.67 lbs.)......	118.12 "
16.	Force of draught in inches of water (natural draught)	0.60 in.

AVERAGE TEMPERATURES.

17.	External air	75.5° Fahr.
18.	Fire room..	85.0° "
19.	Steam	339.8° "
20.	Escaping gases	389.9° "
21.	Feed-water	190.2° "

FUEL.—Bituminous run of mine coal, from Athens, Ill.

22.	Total coal consumed	9,298 lbs.
23.	Moisture, 7.45 per cent..........................	693 "
24.	Dry coal consumed................................	8,605 "
25.	Total refuse—1,046 plus 38	1,084 "
26.	Total combustible................................	7,521 "

		By Ultimate Analysis.		By Proximate Analysis.	
27.	Heating value of 1 lb. coal....	9,750	B.T.U.	10,830	B.T.U.
28.	" " " dry coal	10,535	"	11,700	"
29.	" " " combustible ...	12,053	"	13,389	"
30.	Total heat in fuel	90,655,500	"	100,697,340	"

RESULTS OF CALORIMETRIC TEST.

31. Quality of steam (dry)................ .... 1.00

WATER.

32. Weight of jacket steam returned to boilers..................	5,376 lbs.	
33. Weight of water pumped to boilers	50,382 "	
34. Total wt. of water fed to boilers at 190.2° F. (This includes 5,035 lbs. of fresh feed-water fed into hot well from water mains, to make up losses by leakage, etc.)	55,758 lbs.	10,638,626 B.T.U
35. Estimated leakage from blow-off cocks and flues, in water, at 339.8° F	2,750 "	935,000 "
36. Total heat above 0° F. in the 53,008 lbs. of water actually evaporated, at 103.45 lbs. pressure		64,542,541 "
37. Total heat derived from fuel, 64,542,541 less 10,638,626, plus 935,000, equals.........		54,838,915 "

Of this total heat, a portion was used to drive the main pumping engine No. 612; the remainder was expended in driving the several auxiliaries, or lost by leakage, condensation, radiation, etc.

This total heat the writer has divided into three classes, as follows:

Class A.— Expenditures or losses of heat properly chargeable to boilers, and which should be deducted from the total heat derived by them from the fuel (Item 37) before calculating their net evaporation or efficiency.

38. Heat used by boiler feeder No. 1, as follows—

	B.T.U.	B.T.U.
Heat in 3,381 lbs. steam, delivered to pump No. 1, at boiler pressure	4,116,706	
Heat in exhaust from pump No. 1,	3,636,780	
Net heat used by boiler feeder No. 1	479,926	479,926

39. Heat lost by condensation, as shown by water returned by steam trap, as follows—

Heat originally in 1,105.5 lbs. of water and steam returned, at boiler pressure..............	1,346,057	

Heat in water and steam, as returned by traps	361,743	
Net heat lost by condensation, etc.	984,314	984,314
40. Heat in water leaking from blow-off valves and flues in boilers, 2,750 lbs. at 340° F		935,000
41. One-half of heat lost by leaky valve-stem on main line—		
Total heat in steam, 10 lbs., at 103.45 lbs.	12,176	
Total heat in water, 25 lbs., at 340° F	8,500	
One-half of this	20,676 equals	10,338
42. One-half of leakage through valve to pump No. 8, 160 lbs. steam at boiler pressure	194,826	
One-half of this		97,413
43. One-half of heat lost in overflow and blow-off of hot well, 1,000 lbs. steam at atmospheric pressure	1,178,910	
200 lbs. water at 140° F.	28,000	
Total loss	1,206,910	
One-half of this		603,455
44. One-half of heat lost by radiation and other losses not accounted for.		
Total such losses	2,526,978	
One-half of this		1,263,489
45. Total heat Class A, B. T. U.		4,373,935

Class B.—Expenditures of losses of heat properly chargeable to pumping engines, and which should be added together before calculating the net duty or efficiency of the pump No. 612.

	B.T.U.	B.T.U.
46. Heat used by No. 612 pump in steam cylinders, 34,428.8 lbs. of dry steam at boiler pressure containing	41,920,507	
Heat returned in condensed steam water at 55° F.	1,893,584	
Net	40,026,923	40,026,923

47. Heat in jacket steam, 5,376 lbs. Jacket steam containing	6,545,817	
Heat returned in condensed jacket steam	235,313	
Net heat	6,310,504	6,310,504
48. Heat used by air compressor No. 5, 65.4 lbs. steam, containing	79,631	
Heat in exhaust steam	64,103	
Net heat used	15,528	15,528
49. Heat used by jacket pump No. 6, 84.0 lbs. steam, containing	102,278	
Heat in exhaust steam	22,375	
Net heat used	79,903	79,903
50. Heat used by vacuum pump No. 10, 2,758 lbs. steam, containing	3,358,141	
Heat in exhaust	2,460,108	
Net heat used	898,033	898,033
51. Heat used by air pump No. 11, 333.3 lbs. steam, containing	405,826	
Heat in exhaust	356,864	
Net heat used	48,962	48,962
52. Heat lost by condensation in lines to auxiliaries, etc., in steam leaking past valves and stuffing boxes, blown off at cylinder cocks, etc., 570 lbs., containing 694,032 (B. T. U.)		694,032
53. One-half of heat lost by leaky valve stem on main line. (See item 41)		10,338
54. One-half of heat lost by leak in valve to pump No. 8. (See item 42)		97,413
55. One-half of heat lost in overflow and blow-off of hot well. (See item 43).		603,455
56. One-half of heat lost by radiation and other losses not accounted for. (See item 44)		1,263,489
57. Total heat Class B in B. T. U		50,048,580

Class C.—Expenditures or losses of heat incident only to these tests, and which are not properly chargeable either to boilers or engines.

	B.T.U.	
58. Heat lost in steam consumed by calorimeter, 310 lbs., containing	377,456	377,456
59. Heat lost in steam used to take indicator cards, 10 lbs. at 43 lbs., containing	11,967	11,967
60. Heat used by boiler feeder No. 2, 441 lbs. steam, containing	536,962	
Heat in exhaust steam	509,985	
Net heat used	26,977	26,977
61. Total heat, Class C, in B. T. U.		416,400
62. Total of Classes A, B and C, 4,373,935 plus 50,048,580, plus 416,400, equal to total heat derived from fuel by boilers (see Item 37)		54,838,915

	By Ultimate Analysis.	By Proximate Analysis.
63. Efficiency of furnaces and boilers without allowing for any losses, figured from total heat derived from fuel, as follows— $\frac{\text{Item 37}}{\text{Item 30}}$ equals	60.49 per ct.	54.46 per ct.

64. Gross evaporation from and at actual temperatures and pressures, per lb. of dry coal	6.16 lbs.
65. Gross equivalent evaporation from and at 212° F. per lb. of dry coal	6.60 "
66. Gross equivalent evaporation from and at 212° F. per lb. of combustible	7.51 "
67. Net heat derived by boilers from fuel after charging to them all the heat under Class A, 54,838,915 less 4,373,935, equals	50,464,980

	By Ultimate Analysis.	By Proximate Analysis.
68. Net efficiency of furnaces and boilers, allowing for all losses— $\frac{\text{Item 67}}{\text{Item 30}}$ equals	55.67 per ct.	50.12 per ct.

69. Equivalent net evaporation in lbs. of water from actual temperature and at boiler pressure	49,119 lbs.
70. Equivalent net evaporation in lbs. of water from and at 212° F.	52,238 "
71. Net evaporation, after allowing for heat under Class A from and at actual temperature and pressure per lb. of dry coal	5.71 "
72. Net equivalent evaporation from and at 212° F. per lb. of dry coal	6.07 "

73. Net equivalent evaporation from and at 212° F. per lb. of combustible.............................. 6.91 lbs.

RATES OF COMBUSTION AND EVAPORATION.

74. Dry coal actually burned per square foot of grate surface per hour.................................. 21.16 lbs.

75. Gross rate of evaporation, not allowing for losses, from and at 212° F. per square foot of heating surface per hour.................................. 2.93 "

76. Net rate of evaporation, allowing for all losses under Class A, from and at 212° F. per square foot of heating surface per hour................. ..... 2.69 "

COMMERCIAL HORSE POWER.

77. On basis of 30 lbs. of water per hour, evaporated from temperature of 100° F. into steam at 70 lbs. gauge pressure (34¼ lbs. from and at 212° F.), without allowing for losses under Class A........... 236.8 H.P.

78. Same, allowing for losses under Class A........... 218.0 "

79. Horse power, builders rating at 6.92 square feet heating surface per H. P......................... 400.0 "

80. Total number of complete strokes or revolutions of pumping engine No. 612 during trial........... 8,773

81. Total number of gallons of water pumped during trial, calculated from plunger displacements...... 1,895,407

PERCENTAGE OF SLIP.

82. Leakage past valves .... 0.17 per ct.
Leakage past plungers.............. 2.48 "

Total percentage of slip........... 2.65 per ct. 2.65 per ct.

83. Actual gallons pumped during trial ... 1,845,179

84. Head against which water was pumped, elevation in reservoir (316.24 ft.), less elevation in well (18.78 ft.), plus friction head (6.93 ft.), equals...... 304.39 ft.

85. Total net work done in raising water by pumping engine during trial....... 4,680,460,420 ft. lbs.

86. Net horse power of pumping engine .... 337.7 H.P.

87. Average mean effective pressure in high pressure cylinders, taken from indicator cards............ 40.61 lbs.

88. Average mean effective pressure in low pressure cylinders, taken from indicator cards .... 15.24 "

89. Indicated horse power of pumping engine No. 612..384.41 H.P.

90. Engine efficiency, by plunger displacements........90.25 per ct.

91. Net engine efficiency, deducting slip—

$$\frac{\text{Item } 86}{\text{Item } 89} = \frac{337.7}{384.41} \text{ equals } \ldots\ldots\ldots\ldots\ldots\ldots\ldots 87.85 \text{ per ct.}$$

92. Feed-water from and at 212° F. corresponding to heat units supplied to pumping engine and auxiliaries, and to make up for all losses—

$$\frac{\text{Item } 57}{966} = \frac{50{,}048{,}580}{966} \text{ equals } \ldots\ldots\ldots\ldots\ldots\ldots 51{,}810 \text{ lbs.}$$

93. Equivalent feed-water from and at 212° F. consumed per net horse power per hour.................... 21.91 "
94. Equivalent feed-water from and at 212° F. consumed per indicated horse power per hour.............. 19.25 "
95. Net duty of pumping engine, allowing for all losses, in ft. lbs. per 1,000 lbs. steam, from and at 212° F.......................... 90,339,000 ft. lbs.
96. Net duty, allowing for all losses, per 100 lbs. fuel .... 50,337,300 "
97. Net duty, allowing for all losses, per 100 lbs. dry coal.................................. 54,392,000 "
98. Net duty, allowing for all losses, per 1,000,000 British thermal units..................... 93,518,000 "

DISCUSSION OF RESULTS.

Performance of Boilers and Furnaces.—Referring to Item 63, the total heat derived from the fuel by the furnaces and boilers, divided by the total heat in the fuel, shows an efficiency, not allowing for steam for boiler feeder, leakage, and all other losses, of 60.49 per cent., or of 54.46 per cent., according to whether the heating value of the fuel is figured from its ultimate or proximate analysis.

Allowing for all these losses, the net efficiency would be 55.67 per cent., or 50.12 per cent., according to method of figuring heating value of the fuel.

From page 634 of Kent's Mechanical Engineers' Pocket Book, I quote the following:

"In practice, with good anthracite coal, in a steam-boiler perfectly proportioned, and with all conditions favorable, it is possible to obtain in the steam 80 per cent. of the total heat of combustion of the coal. * * * With most coals of the Western States, it is with difficulty that as much as 60 per cent. or 65 per cent. of the theoretical efficiency can be obtained without the use of gas producers."

According to this, the gross efficiency of from 54.46 per cent. to 60.49 per cent., or the net efficiency, after allowing for all losses, of from 50.12 per cent. to 55.67 per cent., would seem, all things considered, a fairly good performance for the furnace and boilers, in view of the class of fuel used and the condition of the boilers.

Performance of Pumping Engine No. 612.—Allowing for all losses and for the use of steam by the necessary auxiliaries, the net duty per 1,000 lbs. steam from and at 212° F. is seen from Item 95 to be 90,339,000 ft. lbs., while the net duty per 1,000,000 British thermal units, is 93,518,000 ft. lbs.

While the writer has never seen the specifications for these pumping engines, nor any record of a previous duty test, it has always been understood that the engines were "100,000,000 duty engines," and that the rating was based on a steam pressure of 115 lbs. Extreme suction lift due to low water for a long period previous to the test, and the consequent necessity of pumping slowly, had resulted in carrying the steam at the pumping station at a considerably lower pressure. The test was made at this lower pressure. With 115 pounds, and a slightly higher piston speed, it is altogether likely that the net duty would have been not less than 98,000,000 ft. lbs. per 1,000 lbs. steam from and at 212° Fahr., or 101,000,000 ft. lbs. per 1,000,000 British thermal units.

The slip of 2.65 per cent. (Item 82), nearly all of which was past the water plunger, is due to the wear of the plungers and plunger barrels, and their corrosion by the water during the six years they have been in service. This is not excessive. If the pumps were new the slip would probably be less than 1 per cent. Under these circumstances, and with steam and cut-offs at most economical points, they would have shown a net duty of from 1 per cent. (if calculated from steam from and at 212° Fahr.) to 3 per cent. (if calculated per 1,000,000 B. T. U.) in excess of their rating.

The losses in Items 41, 42, 43 and 44, and 53, 54, 55 and 56, amount to 3,949,390 B. T. U., or 7.2 per cent. of the total heat derived from the fuel by the boilers. These losses, resulting from leaks, radiation, condensation, etc., principally in the steam pipe system, are really due in great measure to no defects either in pumps or boilers; but as they were part of the actual losses in the operation of the plant, they have been divided equally, in the above results, between the pumps and boilers.

It is needless to say that in tests as ordinarily made, neither pumps nor boilers would be charged with these losses, and in comparing the results given above with those reported in other tests, this should be borne in mind, and the proper credit should be given to the boilers and pumping engines.

In the light of the information furnished by the tests, the following changes were made in the feed-water return system.

It was considered of first importance to diminish the deposition of scale and oil in the boilers. To accomplish this, the writer decided to use as much condensed steam, and as little fresh feed-water, as possible; to separate the oil from the condensed steam (which has no scale-forming ingredients); and to remove the carbonates and sulphates from the fresh feed-water (which has no oil), treating the two separately before allowing them to mix in the boilers. With a view to reducing the losses of condensed steam, the exhaust of the electric light engine is run into the condenser of the main pumping engine that happens to be working at the time, while the exhaust from pump No. 8 is brought into the hot well. These exhausts were previously wasted. The capacity of the hot well has been greatly enlarged by the connection with it of two large tierces set against the rear wall of the boiler room. It was at first hoped that these tierces, into which the condensed steam from the pumping engines is pumped before it goes to the hot well, might serve as oil-traps for the oil in this water; but a trial showed that the emulsion of the oil and the water could not be separated by gravity. Arrangements are now made to remove as much of the oil as possible by filtration in the tierces themselves. A portion of the oil in the exhaust steam from the auxiliaries is removed by the Austen separator set on the exhaust pipe line from these pumps to hot well.

The fresh feed-water (which has been reduced at this writing to from 2 to 4 per cent. of the total feed-water), is forced by the pressure in the mains, through a 50 H. P. Hoppes live steam purifier, purchased for the purpose, which removes a considerable portion of the salts of lime and magnesia. The advantage of treating the fresh and condensed feed-water separately will be apparent when it is remembered that if all the feed-water had to be treated to remove the salts, a purifier of 800 H. P. would have been required to do the work now done, and with a margin to spare, by the one of 50 H. P.

A Worthington hot water meter is set on the feed-water line from the hot well, and a small Crown meter measures the fresh feed-water before it goes to the purifier. This little meter plays an important part in the economical operation of the plant; for an excess in its registration during any man's watch means either that pipes or valves are leaking or that the man has been negligent; and each man is encouraged to reduce the meter readings to a minimum. Leaks that formerly went undetected for long periods — owing to the very large number of pipes and valves in the system — are now promptly discovered.

As a result of these changes, the boilers now show, at the close of six weeks' run, not more than 1-32 inch of scale, and this without the use of any boiler compounds whatever. Automatic lubricators on all auxiliaries have largely reduced the oil consumption, and a still further saving will undoubtedly be effected when the oil filters are in operation. The tests developed the fact that boiler feeder No. 1 had a slip of 77.6 per cent., due to blow-holes in plunger, and wear in plungers and water cylinders. These defects have been remedied, and the slip probably does not now exceed 25 per cent.

A system of flue gas tests under different conditions of draught, air-admission, and firing, will probably result in some slight economy in coal.

It is estimated that the savings in fuel from these flue gas tests; from the changes in steam pressure and cut-off; from the removal of scale from the boilers and the repairs to boiler feeder No. 1, will result in a saving of from 10 per cent. to 15 per cent. of the coal bill — or, say, $450 per annum. The saving in boiler compound will amount to $175 more, and the yearly saving in oil to perhaps $50 — or a total of $675 per annum. The total cost of the test and testing instruments, including thermometers, mercury column; flue gas sampler and apparatus for gas analysis; iron door in breeching or flue; standardization of instruments; all labor and materials of every sort, and oculist's bill for treatment of two engineers whose eyes were injured while testing thermometers, was $250.20. The cost of the changes in the feed-water returns; additions to the hot well; the Hoppes feed-water purifier, and all other changes of every sort in the system, was $410.14. All of this latter amount, as well as such portion of the $250.20 as was invested in instruments or apparatus still in stock, may be considered as spent in permanent improvements to the plant. The total of all the expenditures was $660.34. The economies resulting, not counting the improvement in discipline and education of the Pumping Station force, nor the general benefits in added life of boilers and improvement of plant, will probably give a return of 100 per cent. on the investment in the first year, and would have been proportionately greater had the operation of the plant been less economical than the tests showed it to be.

3 0112 072690487